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AGGREGATE, CEMENT AND CONCRETE RESEARCH IN CANADA 1980

FINAL REPORT

by

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CHAPTER 1

INTRODUCTION

In 1981, the present author wrote a report on the work of CANMET in relation to long-term applied research activities of other agencies in the field of construction materials of mineral origin in Canada. In preparing the report it was necessary to obtain a clear picture of work done by the various Federal, Provincial, industrial, and university research organizations and laboratories in Canada. The data collected are collated in this report so as to present concise information on long-term applied research in the fields of aggregate, cement, and concrete carried out in Canada in 1980.

Before describing the research done, it is useful to review briefly the cement, aggregate and concrete industries in Canada.

Concrete industry in Canada has been in existence for a century, the first Portland cement plant being established in Hull, Québec in 1889. At present, there are 24 cement plants with 51 kilns in Canada, located in all Provinces except Prince Edward Island. The production of cement in 1978 was 10.5 million tonnes valued at $572 million. In the 1970s many technological advances were made by the Canadian cement industry and new equipment was installed. Continuing export of cement to the U.S. was advantageous.

It may be worth noting the degree of foreign ownership of the Canadian cement and concrete industry: more than one-half of Canada Cement Lafarge and of Genstar and almost one-half of St. Lawrence Cement are foreign-owned.

Aggregate is produced by about 300 firms ranging from 20,000 to 4 million tonnes per year. All districts are served by local pits and quarries with delivery distance rarely in excess of 50 km. In 1974, the total consumption of sand and gravel, stone and cement in Canada was about 340 million tonnes, or 15 tonnes per head.

There is little lightweight aggregate manufactured in Canada; in recent years, some plants have closed down but others have been opened. In 1979, there were eight plants in operation with the production of expanded clay, shale and slag totalling 521,000 m^3 and a value of $8.5 million.

It is relevant to note that ready-mix concrete suppliers are generally small firms: 40 to 60 trucks in metropolitan areas and possibly only six in rural districts. According to the report of the Sector Task Force on the Canadian Cement and Concrete Industry, the numbers of employees in 1975 were distributed as follows:

Number of employees	Number of plants
1-9	120
10-19	102
20-49	90
50 or more	44

Many block plants are also small and sell in a local market. Precast concrete plants producing structural elements are larger and typically have 50 to 100 employees but some are larger still and ship their products over a distance of several hundred kilometres.

There is one special feature of the Canadian cement, aggregate and concrete industry: the so-called vertical integration. The following description has been given in a report by the Sector Task Force on the Canadian Cement and Concrete Industry.

"Vertical integration is a significant feature of the cement and concrete industry. The five largest cement companies own or control an undisclosed number of ready-mix, concrete and aggregate business establishments, estimated at 30 per cent of the total number of establishments with perhaps 60 per cent of

the value of output. This integration is concentrated in the metropolitan areas and the larger business establishments. Independent producers of ready-mix and concrete products are typically smaller producers in the large cities, or medium to small producers in smaller centres. In contrast, a number of large producers of aggregate are not integrated with other businesses."

"Vertical integration in the sector began about 1958 with the cement companies buying out their largest customers, ready-mix companies, to protect their shares of the cement market. Since ready-mix concrete consumes about 70 per cent of Canada's Portland cement, there has been a large incentive for this integration step. The concrete products industry is a smaller consumer of cement and consequently there has been less vertical integration there. Other acquisitions or expansions have been in the trucking business and in aggregate production to control major cost elements. For example, from the standpoint of ready-mix or concrete products manufacturers, the cost of aggregate ranges from 11 to 22 per cent of the total cost of materials. In a more extreme example, the cost of transporting aggregate by truck may range from 30 to 100 per cent of the sum of other costs."

"In the case of aggregate, while some producers are affiliated with the cement and concrete sector, an important number of companies are primarily concerned with aggregate for other purposes such as road-building, bases for building foundations and railroad ballast. Concrete accounts for only about *20 per cent* of the aggregate supplied for all construction purposes. Aggregate and concrete production are therefore connected to an important extent, but there are many producers of aggregate to whom demand from the concrete industry is incidental."

To put the size of the industries discussed in a proper perspective we can note that in 1976 the value of the metallic and non-metallic mineral industry was about $16.2 billion, of which the cement, aggregate, and concrete

components accounted for about $1.8 billion or 11 per cent of the total production value of the metallic and non-metallic mineral industry.* The number of people employed in the industry was about 23,000 or 12 per cent of the total of about 197,000 who were employed in 1976 by the metallic and non-metallic mineral industry.

Since the cement, aggregate and concrete industry is a supply industry to the construction industry, the cement, aggregate and concrete activity is very largely dependent on the overall construction activity. While this is also true of structural steel, the steel industry, unlike the cement industry, has many non-construction outlets.

Data on cement-use, according to the type of construction in Canada, are not readily available but U.S. data for 1976, reported by the U.S. National Materials Advisory Board report, published in 1980, may be of interest. The percentage of cement use according to the type of construction is as follows:

residential	31
industrial and commercial	24
public buildings	7
other construction	17
highways	16
miscellaneous	5

Some statistical data for Canada are given in Tables 1 to 4.

From the above, we can see the cement, aggregate and concrete industry in Canada as adequate to satisfy Canada's needs and also able to export cement. The concrete industry is fragmented by the type of activity, and, in addition,

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* Data from G. W. Riley, Manager, Mineral Processing Laboratory, Mineral Sciences Laboratories, CANMET.

within practically every type, there is a large number of small firms, as well, of course, as some large ones, but no very large ones. This fragmentation is modified by vertical integration. The degree of foreign ownership should also be noted. All these factors influence the industry's attitude to research.

In the following chapters, a detailed account of long-term applied research on aggregate, cement, and concrete is given: Chapter 2 deals with Federal Government agencies, Chapter 3 with Provincial agencies and Crown corporations, Chapter 4 with universities, and Chapter 5 with industry.

Table 1: Annual value of construction between 1971 and 1980*

Year	New works	Repair	Total construction	Per cent variation in current dollars	Total construction as percentage of Gross National Expenditure	
	Millions of current dollars				in current dollars	in constant 1971 dollars
1971	13,276	2,589	15,865	15.1	16.8	16.8
1972	14,469	2,820	17,289	9.0	16.4	16.3
1973	16,954	3,220	20,174	16.7	16.3	16.0
1974	20,772	3,921	24,693	22.4	16.7	16.0
1975	24,056	4,320	28,376	14.9	17.2	16.2
1976	28,145	4,986	33,131	16.8	17.3	16.2
1977	30,130	5,673	35,803	8.1	17.1	15.8
1978	31,910	6,280	38,190	6.7	16.6	15.2
1979	35,471	6,900	42,371	10.9	16.3	15.0
1980	38,796	7,622	46,418	9.6		

* from Statistics Canada 64-201

Table 2: Value of various types of construction in 1977*

Type of construction	Value $ millions	Per cent of total
Building		
Residential	13,126	36.7
Industrial	1,729	4.8
Commercial	3,639	10.2
Institutional	1,662	4.5
Other building	1,152	3.2
Total building construction	21,308	59.5
Civil Engineering		
Marine	242	0.7
Highways and airport runways	2,691	7.5
Waterworks and sewerage	1,669	4.6
Dams and irrigation	154	0.4
Electric power	3,401	9.5
Railways and telephones	1,356	3.8
Gas and oil facilities	2,724	7.6
Other engineering construction	2,259	6.3
Total engineering construction	14,497	40.5
TOTAL	35,804	100.0

* from Stonehouse, *Cement*, 1979

Table 3: Production of cement in Canada*

Province	Number of plants	Production of cement in 1978	
		tonnes thousands	value $ thousands
Newfoundland	1		5,685
Nova Scotia	1		12,128
New Brunswick	1		12,643
Québec	5	2,809	130,147
Ontario	7	3,953	183,110
Manitoba	2	681	34,544
Saskatchewan	1	353	24,689
Alberta	2	1,167	113,537
British Columbia	4	1,019	56,107
Canada total	24	10,558	572,590
Type of cement			
Portland		10,191	
Masonry ‡		367	

‡ includes small amounts of other cements
* after Stonehouse, *Cement*, 1979

Table 4: Size of the concrete industry in 1978*

Segment of industry	Number of establishments	Number of employees	Value of production $ millions
Cement	29	2,873	526
Concrete products (block, brick, pipe, tanks, poles)	499	8,265	533
Ready-mix concrete	440	7,471	762

* after Statistics Canada 44-204, 44-205 and 44-211

CHAPTER 2

LONG-TERM APPLIED RESEARCH IN FEDERAL GOVERNMENT AGENCIES

The Federal Government contributes to long-term applied research on aggregate, cement and concrete directly only through two bodies: the National Research Council and CANMET. Each of these agencies does in-house research and also gives support for research to be done elsewhere; in the case of the National Research Council this is through the grants of NSERC and in the case of CANMET a small number of outside contracts is arranged.

One other Federal agency should be mentioned: PFRA (Prairie Farm Rehabilitation Administration). The work of this organization in the field considered is very limited and mainly of interest to the Prairie Provinces.

Table 5 summarizes the research done, together with the effort expended in dollars and man-hours per annum by each agency. A list of people interviewed at NRC, at PFRA and at CANMET is given in Appendix A. An account of the research described at these interviews is presented after Table 5.

At the Prairie Farm Rehabilitation Administration (PFRA), Saskatoon, I saw Mr N. Peters, Chief, Geotechnical Division, and Mr J. R. Scoular, Concrete and Quality Control Engineer. Work here has been in progress for more than 20 years in the field of use of fly ash in concrete under sulphate attack and the project is still continuing. It is estimated that a further five man-years will be required for the preparation of the report which should give a comprehensive picture of the effects of a wide range of variables upon the sulphate resistance of concrete made using partial fly ash replacement and Types I and V cements.

Information on work done in the Division of Building Research at the National Research Council (NRC) was obtained from Dr V. S. Ramachandran, Head, Materials Section. The work done there is mainly in the nature of basic research but a brief mention may be interesting.

Table 5: Long-term applied research in Federal agencies

Agency	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
National Research Council	New test methods for alkali-reactive aggregates	Mechanism of reactivity and basic properties of fly ash: accelerators or catalysts for hydraulic reaction of fly ash Mica-reinforced cement studies Basic work on admixtures Basic mechanism of frost action and use of incorporated fine materials in lieu of entrained air *continued . . .*	Investigation of frost damage in parking buildings	*see continuation*	

Table 5 (*continued*): Long-term applied research in Federal agencies

Agency	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
National Research Council *continued*		Study of corrosion from physical-chemical standpoint and accelerated assessment of durability		Total for all projects	
				3.5	120,000
Canada Centre for Mineral and Energy Technology (CANMET)	Use of marginal aggregates and of waste materials as aggregate Lightweight aggregate of economic value in Canada	Energy conservation in construction industry, including use of fly ash, slag, silica dust and superplasticizers CSA comparative cement: sample program	Behaviour of Portland and high-alumina cement at ambiant and elevated temperatures Long-term performance of concrete in marine environment		
		continued . . .	*continued . . .*	*see continuation*	

Table 5 (*continued*): Long-term applied research in Federal agencies

Agency	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
Canada Centre for Mineral and Energy Technology (CANMET) *continued*		Performance of Canadian fly ash	Performance of concrete in acidic waters of Northern Canada In-situ strength determination Effect of low temperatures on concrete, especially in relation to the length of the freezing cycle	Total for all projects 9.0	450,000 +75,000 for contracts

continued

Table 5 (*continued*): Long-term applied research in Federal agencies

Agency				Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
Prairie Farm Rehabilitation Administration		Use of fly ash in concrete under sulphate attack made with Types I and V cement (20 year project)		0.2	6,000
TOTALS 4	3	9	10	12.7	651,000

The topics covered include the mechanism of reactivity and basic properties of fly ash but the studies are not particularly concerned with the types of fly ash available in Canada. One of the objects of the work is to discover accelerators or catalysts for the hydraulic reaction of fly ash.

Work is also done on the basic mechanism of frost action and on the use of incorporated fine materials in lieu of entrained air. Some of the investigations on frost action include assessment of damage in parking garages.

Another topic is that of mechanism of attack of concrete by sulphates and chlorides. Studies are also made of mica-reinforced cement and on the development of new test methods for alkali-reactive aggregates. Work at NRC is done on admixtures, and on corrosion, particularly from the physical-chemical standpoint. Some of the data on corrosion of parking buildings are bought from outside bodies but NRC now monitors further progress of corrosion.

A list of general topics worked on at NRC would cover:

a) Basic properties of concrete.

b) Durability to frost action in concrete and other porous materials.

c) Performance of building materials as revealed by their microstructure and composition.

d) Performance of concrete as related to the chemical processes in cements.

e) Physical and mechanical properties of repair systems.

f) Performance of Canadian aggregates.

It is difficult to draw a line between the basic research element in the above work and research of an applied nature but all the work done is of a long-term character. The total expenditure is $800,000 per annum and the total effort represents 23 man-years. Probably 15 per cent of the total effort can be classified as long-term applied research, viz. 3.5 man-years and $120,000.

Information on work done at the Canada Centre for Mineral and Energy Technology (CANMET) was obtained from Mr V. M. Malhotra, Head, Construction

Materials Section, Mineral Processing Laboratory and his staff. I also visited the CANMET laboratories.

The work of CANMET in the field of cement, aggregate and concrete can be briefly summarized as follows:

a) Durability of concrete in acidic and pure waters of Northern Canada. (This work is done in collaboration with Hydro-Québec and Société d'Energie de la Baie James and Laboratoire de Béton (see Chapters 3 and 5).)

b) Effect of low temperatures on concrete, especially in relation to the length of the freezing cycle.

c) Accelerated strength testing of concrete.

d) Various pull-out techniques for in-situ strength determination.

e) Performance of superplasticizers in concrete.

f) Performance of high-alumina cement concrete.

g) Measurement of thermal conductivity of concrete.

h) Examination of Canadian fly ashes.

i) Properties of Canadian lightweight aggregates.

j) Assessment of coal mine shale for lightweight aggregate.

k) Sulphur-infiltrated concrete.

l) Long-term performance of concrete incorporating blastfurnace slag.

m) Comparative sample program (with CSA and cement industry) to assess cement specifications and test methods.

Some of these projects are, at present, in the stage of follow-up of a substantial investigation so that the time currently involved in them is minimal.

Some other projects have reached the stage of conferences dealing with dissemination of the research results obtained. Yet other projects are of a very long nature and the effort in any one year may be limited to taking readings on samples.

The above remarks will explain why a wide range of projects is done by no more than nine people with an annual expenditure of $450,000. It should be added that, because of the nature of the organization of CANMET, the Construction Materials Section has access to facilities and time of other sections. Thus the real effort is probably larger than reported.

In addition to in-house research, CANMET contracts out work to other organizations. In the two years 1979-80 and 1980-81, the value of contracted-out work was $113,000. This was distributed as follows: $25,000 to University of Calgary, $50,000 to University of New Brunswick, $12,000 to Queen's University, $11,000 to Laboratoire de Béton, and $15,000 in small contracts. The contracts are all primarily for specific investigational work and only rarely include development.

The value of CANMET contracts in 1980-81 ($75,000) compares with the sum of approximately $3,000,000 awarded in operating and equipment grants to all projects (235 in number) in civil engineering in 1977-78 by NSERC. It is difficult to estimate how many of the projects would be in the area of concrete, cement or aggregate. Amongst the projects in civil engineering listed under the letter 'A' in 'Grants to Individuals', only one (Aïtcin) out of seven fell into one of the above categories. From information obtained from interviews (see Tables 6, 7, and 8) it does not seem that, in 1980-81, NSERC supported many projects in the field of concrete as a material.

The statements about the activities of CANMET made earlier indicate that its work represents a very large part of the long-term applied research on aggregate, cement, and concrete undertaken by Federal Government agencies. The work is of considerable value to a wide range of users and provides a Federal focus for long-term applied research activities. Contracts arranged by CANMET widen the scope and value of the in-house research. The National Research Council complements the work of CANMET and provides a more science-oriented centre of research.

CHAPTER 3

LONG-TERM APPLIED RESEARCH IN PROVINCIAL AGENCIES AND CROWN CORPORATIONS

The work of the Provincial agencies and Crown corporations is, not surprisingly, uneven with regard to research topics. Naturally, such bodies as the Ministries and Departments of Transportation and the Hydro-electric authorities are very much occupied with investigations of concrete. Cement is not studied, apart from work done on the utilization of fly ash in conjunction with Portland cement, and aggregate, too, receives little attention.

A summary of the investigations undertaken by the Provincial agencies and Crown corporations is given in Table 6. Appendix A gives a list of the people interviewed or contacted at these places. A descriptive account of the work being done follows Table 6.

Information about work done in the British Columbia Hydro and Power Authority was given by Mr E. G. W. Bush of Contracts Preparation Section, Hydro-Electric Generation Projects Division. The main activity is concerned with answers to specific field problems arising in the construction of various dams. This includes investigation of aggregate sources, studies of strain capacity, creep, autogenous volume changes, use of admixtures and of fly ash, and also thermal properties of concrete and efficiency of latex compounds for bonding and patching.

Some of the work is done in-house, and the rest by contract, mainly to the University of Calgary and R. M. Hardy Associates (1978) Ltd. The amount of work done fluctuates with the size, or indeed existence, of specific construction projects.

Mr K. A. Lenz from Manitoba Hydro wrote to me that Manitoba Hydro is not engaged in any long-term applied research relating to aggregate, cement or

Table 6: Long-term applied research in Provincial agencies and Crown corporations

Agency	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
British Columbia Hydro and Power Authority	Investigation of aggregate sources	Use of admixtures and fly ash	Creep, thermal properties, strain capacity	3.0	200,000 much contracted out
	All work concerned with field problems				
Manitoba Hydro			Study of long-term performance of concrete in existing structures: air-void analyses, compressive strength tests, and accelerated freeze-thaw tests	not manpower or cost intensive	

continued

Table 6 (*continued*): Long-term applied research in Provincial agencies and Crown corporations

Agency	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
Ontario Hydro	Alkali-aggregate reaction	Utilisation of fly ash (Some CANMET Contracts) Use of cement grout in stabilization of waste and of fly ash slurry for back-fill (AECL Contracts) Temperature rise in cables with differing types of backfill Superplasticizers (CANMET Contract)	Temperature cycling of mass concrete Creep of fly ash concrete	Total for all projects (total 9.0)	(total 500,000) estimated long-term research component 6.0 | 300,000

continued

Table 6 (*continued*): Long-term applied research in Provincial agencies and Crown corporations

Agency	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
Hydro-Québec	All work contracted out; no research laboratories				
Nova Scotia Power Corporation	Alkali-reactive aggregates (see N.S. Technical University, Table 5a)			Work contracted out	
British Columbia Ministry of Transportation and Highways	Standardized format developed to describe aggregate Various tests applied to determine aggregate quality and achieve normalization of tests *continued . . .*		Use of high-alumina cement concrete for bridge deck overlay and other purposes Other specific studies e.g. durability and wear resistance of bridge decks, and cracking of bridge decks	*see continuation*	

Table 6 (*continued*): Long-term applied research in Provincial agencies and Crown corporations

Agency	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
British Columbia Ministry of Transportation and Highways *continued*	Other specific studies, e.g. role in frost heave			Total for all projects: 1.0 (estimate)	30,000 (estimate)
Ontario Ministry of Transportation and Communications	*continued . . .*	*continued . . .*	Deterioration of bridge decks Durability of concrete structures Electrical impedance of concrete Variation of strength in concrete columns		

Table 6 (*continued*): Long-term applied research in Provincial agencies and Crown corporations

Agency	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
Ontario Ministry of Transportation and Communications *continued*		Properties of various cements		Total for all projects	
		Use of blastfurnace slag			
	Influence of aggregate on cracking			8.0	250,000
Ministère des Transports (Québec)			Deterioration of concrete: study of correlation between behaviour of concrete in structures and laboratory tests on aggregate	1.0	30,000
	Alkali-aggregate reaction			1.0	37,000

continued

Table 6 (*continued*): Long-term applied research in Provincial agencies and Crown corporations

Agency	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
New Brunswick Department of Transportation	A fixed concrete laboratory and mobile laboratories for testing				
Centre de Recherche Industrielle de Québec			Development of polymer concrete for use in external wall panels	2.0	65,000
			Development of light-weight polymer concrete		
	Manufacture of expanded clay and shale aggregate in suspension kiln		Efflorescence on concrete block	1.0	35,000

continued

Table 6 (*continued*): Long-term applied research in Provincial agencies and Crown corporations

Agency	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
Research and Productivity Council, New Brunswick		Utilization of local fly ash (proposed)			(Proposed expend-iture: 10,000 to 20,000)
TOTALS 11	8	7	17	23.0	947,000

concrete. Having stated the above, he went on to say that they are very interested in the long-term performance of the concretes in their many hydro-electric generating stations. Through their concrete surveillance and inspection program, they are attempting to correlate life expectancy and the need for present and future repairs, with a measure of the quality of the in-place concretes. Tests being performed on concrete cores recovered from various stations include air-void analyses, compressive strength tests and, in some cases, accelerated freeze-thaw tests.

Work done in the Ontario Hydro Research Laboratory, Civil Engineering Department, covers a wide range of topics. About 70 per cent of work done arises from requirements of other branches of the Ontario Hydro, and consists mainly of testing and development of better techniques; 30 per cent of the work is initiated in the research laboratory itself but topics are discussed with other branches. Thus, not all their work comes under the heading of long-term applied research. There is relatively little collaboration with Hydro-electric authorities in other Provinces but some work, although not of long-term nature, is done with British Columbia Hydro. However, good contacts are maintained via technical committees.

Ontario Hydro has done some work on contract for CANMET, mainly in the area of superplasticizers and also on the use of fly ash in high strength concrete.

Much of their work is concerned with quality control and field and internal research programs for specific small projects. Thus, work done at Ontario Hydro covers a range of topics in the field of concrete and concrete materials. This includes the use of cement and cement grout to stabilize atomic waste fill, and backfilling of electric cables with cement stabilized fly ash slurry. Temperature rise of cables in different types of backfill has been studied. Application of other types of backfill is being investigated. Other research

work is concerned with temperature cycling in mass concrete in order to determine optimum mixes of a given strength; various cements and fly ash have been used. A conduction calorimeter has been developed at Ontario Hydro. Alkali-aggregate reaction is also studied.

Considerable work has been done on utilization of fly ash but this has generally not been successful because of the variability in the quality of fly ash. Specifically, since the power stations are not used for base load, the carbon content of fly ash is very high with the result that the fly ash cannot be used for air-entrained concrete. On the other hand, fly ash obtained in winter is of good quality but there are no possibilities of stocking it until use in the summer.

Fly ash was used in the past for the production of lightweight aggregate within the Hydro but this has proved uneconomical. Other topics include creep of fly ash concrete based on equivalent strength of concrete.

Information on work done at Hydro-Québec was obtained from M. Gaëtan Seguin, Division Head, Concrete Control, Structures and Mechanics. Hydro-Québec is totally different from other Canadian Hydro authorities in that it has no laboratories, does no testing (except on very small projects) and undertakes no research. The Hydro uses private testing laboratories whose work is described elsewhere in this report. One can therefore say that there is no long-term applied research undertaken in Hydro-Québec.

From the Ministry of Transportation and Highways, British Columbia, Dr D. R. Haughton wrote to me about their development projects in cement, aggregate and concrete. He described generally two projects. The first concerns aggregate: its sources have been catalogued in terms of location, land use, surface and subsurface geology, quality and reserves. A further stage, now in progress, examines the physical, chemical and petrographic tests applied to aggregate, which are used to define its quality. This portion of the project

will result in normalization of aggregate quality tests to a fundamental test such as the petrographic test. Geotechnical personnel from each of the six Ministry of Highways Regions throughout British Columbia will continue to provide input into this project.

The second project deals with high-alumina cement concrete. Here, the Geotechnical Branch, in conjunction with the Bridge Branch, Ministry of Transportation and Highways, is investigating the use of high-alumina cement concrete as a bridge deck overlay and also other uses where rapid hardening concrete is desirable.

Other aggregate projects undertaken by the Ministry of Transportation and Highways include joint development and operational pavement design projects, including aggregate beneficiation and aggregate stabilization by chemical or physical means. Aggregate studies relating to the cause and correction of frost heave in highways are also being undertaken. Concrete investigations also include evaluation of latex concrete, the use of lightweight concrete, concrete surface treatments, and corrosion prevention concrete additives.

Since many projects involve both operational and remedial works with development implications, it is not possible to define expenditures solely related to development, but the long-term applied research is not significant.

Applied research in aggregate, cement and concrete is done at the Ontario Ministry of Transportation and Communications. Choice of research projects is made in-house but all the projects are related to practical problems relevant to the Ministry's operation. There is a research and development steering committee which contains people from the Ministry and this gives advice on the choice of projects, but it is not a committee which directly oversees the work.

Most of the research projects undertaken by the Concrete Technology group within the Research and Development Branch are concerned with the durability of reinforced and prestressed concrete structures in the highway environment.

The objective of several projects is to develop recommendations for changes in policies for the construction of new structures and the rehabilitation of existing structures. This involves undertaking research projects to monitor the performance of existing repair techniques, the development and implementation of improved repair methods and the transfer of the developed technology to the site personnel through the production of specifications, manuals and through seminars. It also involves developing alternative methods of improving the durability of new construction and repair procedures, investigating new materials, test methods and processes, and undertaking fundamental research studies in support of the above objectives. There are no active research projects on Portland cement.

A list of projects undertaken recently and still current is as follows:

1. Laboratory investigation of concrete overlays.
2. Detection of concrete deterioration in asphalt-covered bridge decks.
3. Evaluation of demonstration projects - concrete bridge decks.
4. Effect of waterproofing membranes on steel corrosion.
5. Bridge deck restoration manual.
6. Investigation and restoration of deteriorated substructures.
7. Measurement of the electrical impedance of concrete (at Queen's University).
8. Activities in support of the Committee for the Durability of Structures (not funded as separate projects):
   - i) Performance of fibre reinforced membranes.
   - ii) Measurement of cover in reinforced concrete elements.
   - iii) Durability of concrete culverts.
   - iv) Policies for achieving durability of structures.

The following projects have been discontinued:

9. Development of new aggregate durability (at the University of Windsor).
10. Rehabilitation of decks with active cracks.

11. Evaluation of a superplasticizing concrete admixture.
12. Corrosion in the Harmer Avenue bridge beams.

Research activities in concrete technology within the Research and Development Branch have decreased substantially in recent years from approximately 10 man-years and a total budget of $350,000 in 1978 to approximately 4 man-years and a budget of $150,000 in 1980.

In addition, there are several projects which can be described as applied research, and which are carried out by the Concrete Section of the Engineering Materials Office. These projects fall into two categories: those which require the extensive use of laboratory facilities and those directly in support of site functions.

1. Durability of concrete containing granite and gneiss aggregates (Northern Ontario).
2. Use of granulated blastfurnace slag as a partial replacement for Portland cement.
3. Effect of brand of cement on the strength of concrete.
4. Sulphate resistance of blended cements.
5. Durability of lean concrete bases for pavement construction.
6. Adequacy of the air void system in slip-formed concrete barrier walls.
7. D-cracking susceptibility of aggregates in concrete pavements in S.W. Ontario.
8. Variation of strength in concrete columns.

The work done in the Engineering Materials Office involves 4 man-years and about $100,000.

Research on aggregate is undertaken by the Earth and Environment group and there is currently one active project.

At the Ministère des Transports (Québec), activities in concrete come under the Director of Research and Control. As far as concrete is concerned, mainly short-term investigations are undertaken. As for long-term activities, studies

are made of deterioration of concrete and of correlation between the behaviour of concrete in structures and laboratory tests on aggregate using conventional tests. It is also proposed to establish a joint program with the Ecole Polytechnique in Montréal to investigate the alkali-aggregate reaction. The Ministry also adapts foreign techniques and research results to the solution of local problems.

Information on work done in the Department of Transportation of New Brunswick was given by Mr Gerard Keenan, Assistant Highways Director. It appears that no research is done in the Department but there is a fixed concrete laboratory and also mobile laboratories which do routine testing.

Centre de Recherche Industrielle du Québec (CRIQ) is a corporation of the Government of Québec whose main rôle is to contribute to the economic development of Québec by promoting innovation in local manufacturing firms. Although the Centre does not do routine testing it does occasionally do so with a view to facilitating work of industry in initial stages and encouraging research within the industry.

In CRIQ, there is a Division of Materials and Industrial Processes which contains, among others, a group dealing with metals and minerals. In this group, and also in the group dealing with organic materials, polymer concrete is developed for external wall panels, for benches in the Montréal Metro and for manholes. Work is also done on development of lightweight polymer concrete, and very recently work has also started on manufacture of expanded clay and shale aggregate using local materials and a suspension kiln; the latter would allow intermittent operation which it is hoped would be economic, unlike a rotary kiln which has to be operated continuously. A further small project deals with efflorescence of concrete block. No work is done on cement or on conventional concrete.

The Research and Productivity Council is a New Brunswick Provincial

organisation but it is independent of the Provincial government. In the applied sciences department, whose head is Dr Donovan Abbott, work is done on testing of aggregates and of concrete products and on their quality control. Investigations of failures are also undertaken. None of these can be classified as long-term applied research. The only project falling in that category is the proposed work on utilization of fly ash which is produced in New Brunswick and which has an extremely high iron content. Even if the work referred to above were classified as applied research, the expenditure on it would not be large.

It can be seen that, in the Provincial agencies, the effort expended in both man-years and dollars seems low considering the quantity of concrete used by them. However, some of their research work is contracted out to industry or to universities and this is reported under those headings (including the man- and dollar-effort). Moreover, most of the investigations are in the nature of immediate problem-solving, either before or during construction and, subsequently, due to deterioration of their structures in use.

CHAPTER 4

LONG-TERM APPLIED RESEARCH IN UNIVERSITIES

As far as universities in Canada are concerned, I have to admit that I was not able to visit all of them, but I limited myself to those where, from my personal knowledge and from enquiries, some research on concrete is being pursued. These universities are not numerous and the amount of long-term applied research falling within the scope of this report is small, and probably smaller than, say, ten or fifteen years earlier.

The universities visited and the faculty members interviewed or contacted are listed in Appendix A. Table 7 presents a summary of the findings: this includes the level of effort in man-years and dollars per annum. The activity in the universities which I have not visited is probably so small as not to alter the figures quoted by more than a few per cent. A descriptive presentation of the research undertaken is given later in this chapter.

At the University of British Columbia, work in the field of concrete is done by Dr S. Mindess, Associate Professor of Civil Engineering, who has recently been joined by Mr R. Gray, Assistant Professor of Civil Engineering. The achievements of 1979 include the development of a large instrumented impact machine for steel fibre concrete. Also, work is starting on studies of aggregate-paste bond with a view to establishing the permeability along the interfacial surface when water is subjected to pressure of several hundred psi. Although this may be classified as fundamental work, its application to marine structures may be considerable. However, so far, no measureable work has been done. The work is done under contract from Martin Marietta in Baltimore but funds originate from the U.S. Navy.

Work actually done in recent years at the University of British Columbia

Table 7: Long-term applied research in universities

Institution and research worker reporting	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
University of British Columbia (Mindess)	Aggregate-paste bond to establish permeability at interface under high water pressure (initial stages still)	Cement-wood fibre composites Crack propagation in cement and mortar under stress	Development of large impact machine to test steel fibre concrete	Total for all projects 1.4	50,000
University of Alberta	-	-	-	-	-
University of Calgary (Ward)			Freeze-thaw properties of mass concrete	4.0	100,000
			Durability of spun poles, bridge piers, railway ties	0.1	2,000
			Properties of masonry walls	0.5	20,000

continued

Table 7 (*continued*): Long-term applied research in universities

Institution and research worker reporting	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
University of Calgary (Joshi)		Cementitious properties of fly ash		1.5	20,000
			Low-strength concrete using fly ash, lime, Portland cement	1.0	25,000
University of Calgary (Johnston)	Use of fly ash to reduce alkali-aggregate reaction		Freeze-thaw properties of fly ash concrete with air-entrainment	2.0	18,000
			Superplasticizers and waste materials for high strength concrete (CANMET contract)	1.0	24,000

continued

Table 7 (*continued*): Long-term applied research in universities

Institution and research worker reporting	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
University of Saskatchewan (Nasser)		Saskatchewan fly ash as partial replacement for Portland cement		2.0	16,000
		Strength and bond of masonry cement		1.0	5,000
			New techniques and methods for control of concrete	1.0	25,000
University of Windsor (MacInnis)	Specifications for aggregate			Total for all projects	
	Aggregate beneficiation		Creep, shrinkage and durability	3.0	100,000

continued

Table 7 (*continued*): Long-term applied research in universities

Institution and research worker reporting	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
McMaster University	*see* p. 55 (Table 8) and p. 62				
University of Toronto (Mills)		Part substitution of blastfurnace slag and fly ash for Portland cement		0.2	4,000
University of Toronto (Timusk)			Glass-fibre reinforced polymer-modified materials (non load-bearing) Dampness and temperature stresses in foundations of small buildings	Total for all projects 0.2	10,000

continued

Table 7 (*continued*): Long-term applied research in universities

Institution and research worker reporting	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
Queen's University (Hope)	Mix design using aggregates of poor grading	Autoclaving with fly ash (CANMET contract)	Vacuum processing of concrete ISO test method for permeability (CANMET contract) Electrical conductivity (steel corrosion study)	Total for all projects 1.0	 30,000
McGill University	-	-	-	-	-

continued

Table 7 (*continued*): Long-term applied research in universities

Institution and research worker reporting	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
Université de Montréal Ecole Polytechnique (Houde)			Prediction of strength after early freezing and different types of curing	1.5	10,000
	Durability of local aggregate containing shale			0.5	2,500
Université de Sherbrooke (Aïtcin)		Study of superplasticizers	Study of high strength concrete (>100 MPa)	Total for all projects	
			Light-weight concrete with bubble aggregates		
			Use of industrial by-products in concrete	2.8	60,000

continued

Table 7 (*continued*): Long-term applied research in universities

Institution and research worker reporting	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
Université Laval (Pigeon)			Durability when subjected to long cycles of freezing and thawing Properties of cold concrete	Total for all projects 1.2	10,500
University of New Brunswick (Bremner)	Alkali-aggregate reaction of local aggregates (with Department of Geology)		History of structures with deterioration due to alkali-aggregate reaction Strength and deformation of light-weight aggregate concrete, especially under load	Total for all projects 1.1	17,000

continued . . .

Table 7 (*continued*): Long-term applied research in universities

Institution and research worker reporting	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
University of New Brunswick (Bremner) *continued*		Use of fly ash and blastfurnace slag (CANMET contract)		1.0	25,000
Nova Scotia Technical University (Potyondy)	Alkali-aggregate reactivity of specific local aggregates (completed)			0.1	3,000
TOTALS 13	8	10	22	28.1	577,000

includes cement-wood fibre composites for block and panels, and crack propagation in cement and mortar under stress. The latter project is done in collaboration with Dr Sidney Diamond of Purdue University.

The University of Alberta has a large department of civil engineering. According to Dr J. G. MacGregor, Professor of Civil Engineering, no thesis at the MSc or PhD level has been submitted in the field of cement, aggregate, or concrete, in the last five years. No faculty member has had a major grant from NSERC or from other Federal sources for work in this area. Perhaps it is reasonable to point out that the University of Calgary, also in Alberta, does a great amount of work in the relevant area and it is therefore not surprising that the other university in the Province with a Faculty of Engineering has elected not to be active in direct competition with the University of Calgary.

The University of Calgary is active over a wide range of both material and structural aspects of concrete. Clearly, only some of the work is relevant to the present report, but it may be noted that research grants from NSERC, DRB, CANMET, and Canadian Masonry Research Council received during 1980/81 by faculty members of the Department of Civil Engineering totalled $627,000.

Here are some typical examples of the work done.

Dr M. A. Ward, Head of Department of Civil Engineering, is doing work on freeze-thaw properties of mass concrete for Revelstoke Dam in British Columbia. He is also doing work on material characterisation of mass concrete for the Seven-Mile Dam, British Columbia as well as for the Revelstoke Dam. Other projects include durability of spun poles and bridge piers and also the air-void analysis of railway ties. While much of this work is directly related to specific projects, it can be reasonably expected that the advance in knowledge resulting from the work can be generalised and will be useful in future work, and therefore clearly comes under the heading of long-term applied research.

Dr Ward is also doing work in the field of concrete masonry under a

research grant in aid from the Canadian Masonry Research Council in Ottawa, which is financed by the Canadian Masonry Contractors' Association. One of the projects involves prediction of the elastic properties of a wall system from properties of constituents: other projects deal with testing of mini-walls and with masonry mortars.

Some of the work on the rôle of microstructure and composition in the durability and strength of building materials is of fundamental nature but will no doubt have applied consequences. The expenditure is $28,000 per annum, but probably only a small fraction should be counted under long-term applied research at this stage.

The same applies to work on stress-temperature-moisture interactions in concrete materials and on fundamental properties of cementitious material. Thus, of the $17,000 spent per annum on these projects, probably very little comes under the applied research heading.

Fundamental work, but with considerable practical application in the short term, is being done on fly ashes in order to determine the properties which make these ashes cementitious and to develop means of making non-cementitious ashes into cementitious ones other than by the addition of Portland cement. The work is done by Dr R. C. Joshi, Professor of Civil Engineering at the University of Calgary under a grant from the Alberta Environment Research Trust. A somewhat related project is production of low-strength concrete from Western fly ash using cement and lime.

The third project on fly ash concerns durability of fly ash concrete exposed to sulphate attack. This project is beginning.

Other projects on fly ash carried out by Dr C. D. Johnston are concerned with freeze-thaw properties of fly ash concrete when extra air-entrainment is present and with the use of fly ash to reduce the alkali-aggregate reaction. These projects are supported by NSERC; there are also other grants for these

projects and for work on steel-fibre reinforced concrete (material properties and performance in pavement).

As elsewhere in Canada, Dr Johnston is studying the use of superplasticizers; his particular concern is their use in the production of high-strength lightweight concrete incorporating fly ash. This work is done under contract from CANMET.

At the University of Saskatchewan, work in the field of concrete is done by Dr K. W. Nasser, Professor of Civil Engineering. One project is concerned with the use of Saskatchewan fly ash in concrete as a partial replacement of different types of cement. Financial support is obtained mainly from NSERC, but there is also a small grant from Saskatchewan Power Corporation. Work is done also on strength and bond qualities of masonry cement under a grant from the Masonry Association of Saskatchewan.

Over many years, Dr Nasser has been highly successful in development of new techniques and methods for control of concrete with reference to workability, air content, strength, prediction of later strength, and determination of strength in place. This work has resulted in a number of patents and devices.

At the University of Windsor, Dr C. MacInnis, Dean of Engineering and Dr Peter Hudec, Professor of Geological Engineering are the only two faculty members involved in research in concrete and aggregate on a continuing basis. Dr Hudec's work is on aggregates and he has two continuing projects as follows:

a) Development of new aggregate durability specifications for Ontario (supported by the Ministry of Transportation and Communications, Ontario).
b) Development of beneficiation techniques for aggregates (supported by NSERC).

Dr MacInnis has continuing projects in durability, shrinkage and creep of concrete (supported by NSERC).

At the University of Toronto, the situation is as follows. Research on cement, aggregate and concrete is, somewhat surprisingly, done in two sections of the Department of Civil Engineering: the Geotechnical Section and Construction

Section. But even so, it is only one faculty member in each section that is involved in the relevant research. In the Geotechnical Section, this is Mr R. H. Mills, Professor of Civil Engineering, who spends, on average, one-quarter of his time on what he describes as "curiosity oriented" research but, as he says, "some of it is also long-term applied research pertaining to the use of blastfurnace slag and fly ash in part substitution for Portland cement". Judging by the titles of papers recently presented, or about to be presented, at meetings by Mr Mills, the various investigations are interesting individual studies rather than a sustained applied research effort of a coordinated nature.

In the Construction Section of the Department of Civil Engineering at the University of Toronto, the only research worker in the field of concrete and concrete materials is Dr J. Timusk, Associate Professor of Civil Engineering. In the past, he has done some work on the repair of bridge decks but now works mainly in the area of dampness and temperature stresses in foundations and basements of houses and small buildings (for the Housing and Urban Development Association of Canada) and in the area of glass-fibre reinforced cement-based polymer-modified materials for non-load bearing purposes such as rain screens and architectural finishes. The latter work is supported by several bodies: National Science and Engineering Research Council, Ontario Ministry of Housing, Housing and Urban Development Association of Canada, and some industrial sources. However, the total support from these bodies (some $10,000) is a surprisingly small sum for Federal, Provincial and industrial sources all together to invest in a development program.

Dr Timusk is also active in the preparation of standards for residential or non-engineering concrete but, of course, this is not a research activity. The activity which can be classified as sustained applied research in the fields covered by the present report is probably very small.

Work in the field of concrete at the University of Toronto is done also

in the section of the Department of Civil Engineering which deals with structural design: Dr S. M. Uzumeri, Professor of Civil Engineering, is about to investigate the possibilities of the use of high-strength concrete in offshore structures. However, no research on high-strength concrete as a material is envisaged and Dr Uzumeri does not see himself as a materials researcher.

At Queen's University, Kingston, Ontario, work is done in the Department of Civil Engineering mainly by Dr B. B. Hope, Professor of Civil Engineering. The topics dealt with are as follows:

a) Autoclaving concrete made with fly ash of American origin. This work is financially supported by CANMET.

b) Electrical conductivity of concrete in so far as it is of interest to the study of corrosion of steel in bridge decks. This work is supported by the Ontario Ministry of Transportation and Communications.

c) Mix design using aggregates of poor grading. This work is supported by a grant from NSERC.

d) Vacuum processing of concrete for the purpose of rehabilitation of bridge decks. This work is supported by the Ontario Ministry of Transportation and Communications.

e) Verification of the proposed ISO test method for permeability of concrete with respect to reproducibility. This is work under a CANMET contract.

At McGill University in Montréal, no long-term applied research in the field of cement, aggregate or concrete appears to be pursued, although some such work was done in the past by a faculty member who has since left the University. Teaching in the subject of concrete and concrete materials is carried out by Dr M. S. Mirza, Professor of Civil Engineering.

Work done at the Ecole Polytechnique of the Université de Montréal, was reported by Dr Jules Houde, Associate Professor of Civil Engineering. The main projects are as follows:

a) Early freezing of fresh concrete and prediction of the strength of concrete which had frozen at an early stage and was subsequently exposed to different types of curing. The work is financed by NSERC.

b) Study of aggregates in the Montréal area. This work is done in the Department of Mineral Engineering and is funded by the Quebec government. The purpose of this work is to assess the durability of local aggregates containing shale.

c) In future it is proposed to work on creep of concrete with superplasticizers.

Dr P.-C. Aïtcin, Professor of Civil Engineering at the Université de Sherbrooke wrote describing his research work related to cement and concrete technology. Half of his time is devoted to concrete research and, at present, he has a research associate and a technician working full time in this field. As well, three undergraduate students have been working on two research projects related to concrete technology. His main fields of interest are:

a) High-strength concrete (>100 MPa).

b) Superplasticizers (viscosity measurements, lignosulphonate superplasticizers).

c) Lightweight concrete (bubble aggregates).

d) Use of industrial by-products in concrete (ilmenite sand, silica dust).

Most of these research projects are sponsored by industrial companies. The dollar value of the research presently in progress at the Université de Sherbrooke he estimates as between $50,000 and $75,000 for the two last years, but he thinks that in 1981 the dollar value will be about $100,000.

Information about work done at Université Laval, Québec, was given to me by Dr Luc Lachance, Associate Professor of Civil Engineering. The main work relevant to the present report is done by Dr Michel Pigeon, Assistant Professor of Civil Engineering who is studying the durability of concrete subjected to long cycles of freezing and thawing and is also working on properties of cold concrete: this work is supported by NSERC.

Information on work done in the Department of Civil Engineering at the University of New Brunswick was given by Mr T. W. Bremner, Professor of Civil Engineering. The main projects are as follows:

a) A general study of the alkali-aggregate reaction with particular reference to local aggregates. This work is done in collaboration with the Department of Geology at the University of New Brunswick.

b) Investigation of history of structures which show deterioration due to the alkali-aggregate reaction.

c) Strength and deformation of lightweight aggregate concrete with particular reference to the distribution of stresses within the concrete under load.

d) Durability of concrete in a marine environment (CANMET contract).

e) Use of fly ash and blastfurnace slag (CANMET contract).

The laboratories in the Department of Civil Engineering are well equipped to carry out a variety of tests on concrete.

The new scanning electron microscope obtained by the University is being used to study the micro-structure of low density aggregates. Next year, the microprobe will be used to examine the bonding between cement mortar and masonry units.

The Department has worked over the past six years with the Transportation and Natural Resources Departments of the Province on the topic of alkali-aggregate reactivity, and this investigation is to continue with added co-operation from the University Department of Geology.

At the Nova Scotia Technical University, I spoke to Dr J. G. Potyondy, Professor of Civil Engineering. He is no longer active in research on concrete and concrete materials, his last work, not long ago, being an investigation of alkali-aggregate reactivity of specific aggregates done for the Nova Scotia Power Corporation.

It can be seen that, at the thirteen universities listed in Table 7, the

bulk of the investigations were, quite properly, in the field of concrete. Aggregate and cement were relatively little studied and it should be noted that, for the purposes of this table, most of the studies on blastfurnace slag, fly ash, and superplasticizers, were categorized under cement.

More than half a million dollars were spent on this research and 28 man-years of effort expended. However, we should remember that universities do not normally have to take into account the cost of overheads and equipment at their institutions. No doubt, some 'hidden man-years' of technicians' and secretaries' work are also sometimes overlooked. It should also be noted that some contract money may be listed under the university, as well as under the granting body (e.g. Provincial agencies).

One other factor is worth noting. Universities depend on the availability of both their own money and money from agencies giving them contracts to carry out research. They also depend on a supply of postgraduate students to carry out this work. Since the supply of both money and students fluctuates, so does their work which may thus vary more rapidly in quantity and type than industrial or government research.

CHAPTER 5

LONG-TERM APPLIED RESEARCH IN INDUSTRY

In describing the research done by industry, we should realize that most of this is research done for clients. Some of these are Provincial or Federal bodies, others are private firms. However, some companies do carry out research on their own product and its development.

As in the three preceding chapters, Appendix A lists those people in industry interviewed or contacted. The summary of effort and the type of topic studied in long-term applied research by industry are given in Table 8. Details of the various research activities are given following the table.

As far as the cement industry in Canada is concerned, there is a very small laboratory connected with the plant laboratory at St Mary's Cement. The largest, and in all likelihood, the only really active laboratory of the cement industry in Canada is the Canada Cement Lafarge Belville Research Laboratory. All the work done is concerned with the production of cement and the following are the main topics:

a) Development of mineralizers in kiln burning for the purpose of dealing with the build-up of chlorides. (The situation is that, using rock with a chloride as low as 0.04 per cent, a build-up of chlorides in the kiln of up to 25 per cent is possible.)

b) Investigation of the effect of the size of clinker particles. It is known that larger particles have a higher alkali content and it may be desirable to establish the optimum size of clinker particle from this and other considerations.

c) Flowability of cement powder.

d) Improvement of efficiency of milling of clinker by way of increasing the

Table 8: Long-term applied research in industry

Firm	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
Canada Cement Lafarge Ltd		Using mineralizers in kiln burning Study of size of clinker. Improving efficiency of clinker mill Flowability of cement powder Study of energy use in manufacture of cement		Total for all projects 2.0	200,000
Canadian Portland Cement Association: Ottawa Vancouver Halifax	All long-term research carried out by PCA in the United States No projects specifically directed to materials in or for Canada			- -	- -

continued

Table 8 (*continued*): Long-term applied research in industry

Firm	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
Canfarge Ltée		Use of super-plasticizers in air-entrained concrete to obtain high strength Study of mechanism of action of super-plasticizers Retarded mortar	Manufacture of load-bearing concrete with high insulation value - use of polystyrene Improvement of durability by surface coating of concrete moulds	Total for all projects 4.5	500,000 (includes new equip-ment)
Centre of Research and Development in Masonry			New concrete block of sandwich type Work on concrete generally	0.3 1.0	12,000 100,000 (includes new equip-ment)

continued

Table 8 (*continued*): Long-term applied research in industry

Firm	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
Hardy Associates (1978) Ltd		Properties of fly ash with low carbon and high calcium carbonate content		1.0	60,000
		Use of plasticizers: effect of air-void system on durability		1.0	35,000
			Design of mixes Testing of steel fibre reinforced shotcrete	0.3	30,000
Laboratoire de Béton Limité			Durability of concrete in pure and acidic water (CANMET contract - and others)	0.1	7,000
			In-situ strength testing of concrete	0.2	12,000

continued

Table 8 (*continued*): Long-term applied research in industry

Firm	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
Klohn Leonoff			Accelerated testing of shotcrete and grout	0.3	24,000
			Density of fresh and hardened concrete by X-ray emission to determine durability of surface layer	1.0	50,000
B.H. Levelton and Associates Ltd		Work on fly ash and superplasticizers (CANMET contract)	Accelerated curing (CANMET contract)	1.0	30,000
		Admixture systems, grout, hardeners		1.0	35,000
			Specific projects e.g. shotcrete, ultra lightweight concrete, offshore construction, high-strength concrete	2.0	85,000

continued

Table 8 (*continued*): Long-term applied research in industry

Firm	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
National Boring and Sounding Inc	(Routine inspection)			-	-
Standard Slag Cement Co			Sulphate resistance of slag concrete (contract to McMaster University)		1,000
		Use of slag cement for lean concrete		0.4	15,000
Sternson Ltd		Work on ligno-sulphonate admixtures to obtain flowing concrete of not very high strength *continued . . .*		*see continuation*	

Table 8 (*continued*): Long-term applied research in industry

Firm	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
Sternson Ltd *continued*		Lime and calcium sulphoaluminate based expansion additives Fibre-reinforced expansive mortar		Total for all projects 2.0	 70,000
Trow Ltd			Deterioration of horizontal structures (supported by NSERC and Central Housing and Mortgage Corporation)	1.0	30,000

continued

Table 8 (*continued*): Long-term applied research in industry

Firm	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
Warnock Hersey Professional Services	(Investigations of failures of concrete and structures. Testing for Hydro-Québec)			-	-
TOTALS 13	0	13	12+	19.1	1,296,000

capacity of the clinker mill using two air separators in series. This project has a significant energy aspect and some of the research work has been done using funds obtained from the Federal Government and from the Government of Manitoba.

e) Work on optimization of energy used by balancing the energy used in grinding the clinker and the energy used in burning the raw meal. Work is also to be done on high sulphur clinkers.

f) Canada Cement Lafarge is planning to start work on manufacturing cement with a high magnesia content (5 or even 6 per cent) which could be utilized without causing expansion problems.

It may be noted that Canada Cement Lafarge, like all Canadian cement manufacturers, pays dues to the Portland Cement Association (PCA), Skokie, Illinois; the contribution of Canada Cement Lafarge is more than $1 million. No work at PCA is done directly to solve specific Canadian problems.

According to Mr Stanley Cumming, Manager of Engineering Services of the Canadian Portland Cement Association (or of the Portland Cement Association Canadian Operations), long-term applied research for the cement industry in Canada forms a part of the work carried out by the Portland Cement Association Research and Development Laboratory, Skokie, Illinois. No work is physically done in Canada.

It may be noted that nowadays 90 per cent of the work done in the PCA laboratories at Skokie is contract work, rather than basic or applied research work of a general nature. PCA is collaborating with NRC in the investigation of the behaviour of structural concrete members in fire, but there are no projects specifically directed to materials in or for Canada. However, PCA work on the effect of the length of the freezing cycle, on cold weather concreting and on construction in permafrost is clearly of relevance to Canada.

I also met representatives of the Portland Cement Association in

Vancouver, British Columbia and in Halifax, Nova Scotia. They had nothing to add to the report from Ottawa.

Considerable research work in the field of concrete started in June 1979 at Canfarge Ltée. This company is wholly-owned by Canada Cement Lafarge and provides the back-up and development work for the concrete companies manufacturing block and pipes, also for construction companies and ready-mix companies in all of Canada. The following projects are being pursued:

a) Manufacture of concrete which combines load-bearing capacity with a high insulation value: blocks and panels with a density of 600 to 1000 kg/m³ and a strength of about 7 MPa are being developed. Such a material has a very high cement factor (500 to 600 kg/m³), and contains polystyrene in the form of aggregate or sandwich elements. The main practical problems are connected with mixing and workability.

b) Use of superplasticizers in air-entrained concrete to obtain high strengths of the order of 80 MPa with ordinary aggregate. Some of this work is in the nature of basic research on the mechanism of action of superplasticizers.

c) Improvement of durability of concrete by surface coating using a proprietary material, Gelcoat, which is applied to the interior of the mould prior to placing of concrete. This work is of considerable interest for application to formed vertical surfaces. The work is funded by the Institut du Génie des Matériaux, Montréal, and Canfarge provides the manpower.

d) Introduction of retarded mortar into Canada.

e) In future it is proposed to do work on alkali-aggregate reaction and on glass-fibre reinforced material.

All the above work can be classified as long-term applied research for the purpose of developing new products and is distinct from problem solving.

Information on development work in the field of concrete masonry was given by Dr E. L. Jessop, Director-General, Centre for Research and Development in

Masonry which was established in Calgary in 1979. This organisation is mainly doing contract work for the Federal Government and for industry. The chief objective is developing facilities for technical activity in masonry using funds of the Federal Department of Industry, Trade and Commerce. It is estimated that one-half of the work relates to brick and one-half to concrete masonry. Work is proceeding on the development of a new concrete block of sandwich type.

Hardy Associates (1978) Ltd. is a large firm active, among others, in the field of concrete in a number of locations in Western Canada. Dr D. R. Morgan, Manager, Engineering Materials Division, Burnaby, gave information about the activities of the Burnaby, British Columbia Branch. They are investigating properties of fly ash with a low carbon content but very high calcium carbonate content (up to 30 to 40 per cent). Such fly ash is obtained in the North-Western United States and is imported into British Columbia, as well as Saskatchewan.

The fly ash can be made hydraulic by the addition of finely divided limestone: strengths of up to 80 per cent of the strength of Portland cement concrete have been obtained, but there are problems in the control of setting and slump loss.

A second problem investigated concerns the use of superplasticizers in concrete with particular reference to the air-void system and lack of durability even with very low water-cement ratios.

A third project concerns the design of mixes and testing of steel-fibre reinforced shotcrete for use in mines and tunnels. This is development for a specific concrete supplier who markets the material in pre-packed form.

Laboratoire de Béton Limité, Montréal, is a large, well-equipped testing laboratory which provides testing facilities for a great many very large construction projects in Québec. Its President is M. André Bisaillon. In connection with one of the construction projects in James Bay, the Laboratoire

is conducting research on the durability of concrete in pure and acidic waters. This work is done jointly with Hydro-Québec, Société d'Energie de la Baie James and with CANMET. Hydro-Québec and the Société supply equipment, local transportation by means of a helicopter and the site manpower, as well as some funds. The initial program on exposure of cylinders and slabs took two years, and now a more intensive program is under way. Results to-date indicate that concretes with high water-cement ratios have their surface severely attacked so that it becomes very coarse. Even at low water-cement ratios, etching takes place.

Klohn Leonoff is a firm of consulting engineers active in the field of materials in British Columbia and in Alberta. Dr L. E. Rodway, Head, Materials Engineering Division of the firm in Calgary, gave information about projects undertaken by his company. These are:

a) Accelerated testing of shotcrete and grout using the maturity approach.
b) Density determination of fresh and hardened concrete by X-ray emission (application of techniques used for soils) for the purpose of establishing the durability of the surface layer of concrete in place.

Mr P. T. Seabrook of B. H. Levelton and Associates Ltd., Consulting Materials Engineers, gave information on work done in that firm. They employ about 17 people in the field of construction, mainly dealing with concrete. Their research for internal purposes amounts to less than one per cent of annual sales per annum: contract research, including product development, accounts for 15 per cent of annual sales. Investigations for CANMET contracts in the field of fly ash, accelerated curing, and superplasticizers are carried out. Product development is done for private firms, mainly in the areas of admixture systems, grouts and hardeners, as well as development work on specific projects for special types of concrete such as shotcrete, ultra lightweight concrete for offshore construction, high strength concrete and grouts.

The National Boring and Sounding Inc. in Montréal was a geotechnical company but in recent years it expanded into concrete testing and inspection and does also consultancy for associated engineering companies. National Boring and Sounding is an affiliate of the Lavalin group. According to Dr Gilbert Haddad, Chief of Materials Control, the company is not a research organisation but does routine inspection.

Mr George V. Phillips, Vice-President of Standard Slag Cement Company of Fruitland, Ontario, gave information about work done in his company which is the only manufacturer of blastfurnace slag utilizable in concrete in Canada. In that company, no long-term applied research work is done. Their only activity relevant to the present report is work on sulphate-resistance of concrete made with slag which has been done under contract at McMaster University under the direction of Dr J. Emery.

The object of the research (which is still continuing) was to determine the optimum blend of a high C_3A normal Portland cement with Standard Slag Cement Company's "Cementitious Hydraulic Slag". The optimization is on the basis of good sulphate resistance coupled with structural integrity. This work is supported by grants from the Federal Government and the contribution from Standard Slag is quite small. The company has also developed the use of slag for lean concrete and is planning to expand its work in the future.

The problem arose as to what method of test should be used for this research since no agency in North America had taken the Canadian Standards minimum requirements for sulphate resistance and tested them. Therefore, the initial series of tests was to confirm the standard using recommended cement types and blends of high C_3A Portland cements with varying percentage replacements (by mass) of Standard Slag cement. This is a long range concrete test, which has been under way for four years. Paralleling this work, and to accelerate results, other tests on prisms of standard mortar bars were made.

The last series of accelerated testing was brought about by an engineering query as to the sulphate resistance of these blends when the plastic concrete was placed on a sulphate-bearing soil. Again, no North American testing of this condition has been carried out with the appropriate Portland cement types, and only a report from Germany was available.

Sternson Ltd. of Brantford, Ontario is a small company which, according to its technical director, Mr N. P. Mailvaganam, is doing a considerable amount of long-term applied research mainly in the area of admixtures. They are experimenting with the use of lignosulphonates as superplasticizers for the purpose of obtaining flowing concrete of not very high strength. Work is also done on the development and properties of expansive additives using lime-based systems, and the calcium sulphoaluminate approach originated in the USSR and currently used in Japan under the name of the Denka system. Other projects are concerned with fibres in expansive mortar and with slag as aggregate.

The work is mostly product-development oriented and so that part which can be classified as long-term applied research is fairly small. Their product line is broad, with both cementitious and polymeric materials, but the company employs exclusively chemists and a technologist so that it is not able to deal with engineering applications. Sternson Ltd. would be interested in expanding their activity, specifically in the area of blastfurnace slag if financial support, for instance by way of a grant from CANMET, were available. They intend to publish their findings with respect to expansive additives and slump loss in superplasticized concrete.

Work done at Trow Ltd. was described by Mr John A. Bickley, Vice-President of the company. The company does very little research work but it studies deterioration of various horizontal structures, being concerned in surveying the damage they have suffered and in recommending techniques for their repair. Some of this work is supported by NSERC and by the Central Housing and Mortgage Corporation.

Previously, Trow Ltd. did some work under contract for CANMET on the effect of concrete of using crushed sand. This work was done with Mr N. G. Zoldners as consultant. (Mr Zoldners was previously in CANMET.)

Warnock Hersey Professional Services Ltd. in Montréal is a firm concerned with testing and inspection, and the manager of the Construction Materials Department, Dr Rudolph Farsky, oversees testing and inspection as well as investigations in the field of concrete. In addition, a large effort is put into investigations of failures of concrete and of concrete structures. Thus, the firm does very little research, but it does, among others, routine work for Hydro-Québec.

To summarize, we should recall that some industrial organizations undertake contract research only, but others also carry out research on the development of their own products. This is particularly true of Cement Lafarge (a foreign-owned company) who are studying cement production in general and in relation to energy consumption. St. Lawrence Cement and Inland Cement have no research laboratories, but do some work on the use of waste materials in cement production and in concrete.

From Table 8, it can be seen that industry is giving little attention to research into the use of blastfurnace slag. Here again, the general lack of interest in this topic is surprising, given that about 100,000 tonnes of slag may be ground at any one plant per annum. Only about 10 per cent of slag will normally be used, even though it may be of good quality.

There is some interest shown by industry in the use of admixtures and superplasticizers. Fly ash, too, receives some attention. Here again, as with slag, there is a problem of excess of the material. British Columbia actually imports fly ash from Seattle, and much British Columbia concrete contains fly ash. In about ten years' time, there will be ample British Columbia fly ash from the new Hat Creek Plant. Already, in Canada, 3,000,000 tonnes are produced

per annum. Only about 100,000 tonnes of this are used, one-third of it in Ontario (where useable material is in short supply) and the Prairie Provinces. Although fly ash is produced in the Maritimes, it is not used there. Part of the difficulty in utilization occurs because the period of production of the greatest quantity and best quality of fly ash at the power plants (the winter) coincides with the period of minimum activity in the construction industry and the material cannot be stock-piled easily. Moreover, transport over long distances s uneconomical. Fly ash from some plants cannot be used because of fluctuating carbon content. The problem of air-entrainment in fly ash concrete has not been resolved.

The research topic of no interest to industry is aggregate. Even the ready-mix industry has only control laboratories but no research facilities. The commonly heard gloomy comments on the dwindling supplies of satisfactory and accessible aggregate do not yet seem to be taken seriously in the building industry. It is not yet worth while, apparently, investing money in the study of marginal or unorthodox aggregates.

CHAPTER 6

CONCLUDING COMMENTS

First of all, we should attempt to estimate the expenditure on long-term applied research in the fields of aggregate, cement, and concrete in Canada. One approach is to use figures obtained in the author's 1981 study and reported in Tables 5 to 8. These give the following expenditure on long-term applied research in 1980:

Federal agencies	$651,000
Universities	$577,000
Provincial agencies	$947,000
Industry	$1,296,000
	$3,471,000

Allowing for organizations which have not reported, but also bearing in mind the double reporting of some contracts (e.g. CANMET and universities) and some "optimistic" or "over-enthusiastic" estimates, the total figure for Canada is, at most, $4.5 million. This expenditure should be viewed against the value of cement production of $650 million (estimated), the value of construction of $50,000 million (estimated) and GNP of £300,000 million (estimated).

Another estimate is that due to W. G. Plewes, formerly Senior Research Officer in the Division of Building Research of the National Research Council, from whose work Table 9 is derived. Since the information supplied by some organizations was confidential, detailed description or classification is not available. Plewes' data were obtained in 1969 but there is no reason to believe that any radical change has taken place since, as demonstrated by the data for 1975, even less detailed, given in Table 10.

For present purposes, the relevant figure of R & D expenditure from

Plewes' report is that given in column 3 of Table 9, viz. $574,000. Allowing for some expenditure which escaped Plewes, we can take the sum of $600,000. This sum should be considered in relation to the value of the production of cement in the same year of $152 million, the value of construction of $12,214 million and GNP of $72,586 million.

A like analysis for concrete research and production in 1973 does not yield significantly different data. An estimate of the research expenditure is given in Table 10. Deducting the expenditure on basic research and on routine testing, the research expenditure is, say, $1.5 million. The cement production for the same year is $242 million, the value of construction $20,174 million and GNP $120,438 million. The present situation, allowing for inflation, is similar except that the expenditure by the Department of Industry, Trade and Commerce is smaller and by industry itself larger.

All the figures quoted are in current dollars.

The figures for construction include of course materials other than concrete, so that relations of R & D expenditure to the value of cement and to GNP are most appropriate. These are, as follows:

Year	Long-term applied R & D	Value of cement	GNP	Ratio (1):(2)	Ratio (1):(3)
	$ thousand	$ million	$ billion	per cent	per cent
	(1)	(2)	(3)		
1968	600	152	72	0.4	0.0008
1973	1500	242	120	0.6	0.0016
1980	4500	650 (est)	300 (est)	0.7	0.0015

We may well ask whether this level of expenditure is satisfactory. The value of building materials has always formed a substantial percentage of the total value of construction. For example, in 1977, the total value of all

Table 9: Estimated annual expenditures on research in cement and concrete in Canada in 1968 (after W. G. Plewes)

Source of funds	Category				All categories	Percentage of total
	1	2	3	4		
	Thousands of dollars					
NRC university grants	86	7	7	220	320	20
NRC industrial research program						
a) NRC contribution	26	33	23		82	5
b) industry contribution	25	30	32		87	5
NRC in-house	216	162	12	77	467	28
Federal government (other than NRC)		70		80	150	9
Public utilities	10	30	25	85	150	9
Highway departments	42	85	2	32	161	10
Provincial research councils		7	8		15	1
University funds				18	18	1
Municipalities		100			100	6
Industry	15	15	15		45	3
Industry associates		35	1	2	38	2
Others				9	9	1
TOTALS	420	574	125	523	1,642	100

Category 1: Fundamental research on cement, cement paste and concrete.

Category 2: Evaluation of physical and mechanical behaviour of concrete as related to specific applications and problems.

Category 3: Development and improvement of construction techniques and methods.

Category 4: Structural theory, analysis and design.

Table 10: Estimated annual expenditures on research in cement and concrete in Canada in 1973 (from Department of Industry, Trade and Commerce)

Source of funds	Thousands of dollars	Percentage of total
Federal Government		
NRC university and IRAP grants	350	12
NRC in-house	400	13
Department of Industry, Trade & Commerce (PAIT & IRDIA)	250	8
Department of Energy, Mines & Resources - in-house	200	7
Provincial governments		
Public utilities	500	17
Highway departments	500	17
Provincial Research Councils	100	3
Municipalities	200	6
Industry	500	17
TOTAL	3,000	100

materials employed in construction in Canada amounted to $13.5 billion. Concrete represents a large part of this sum, and this means a large need for Portland cement, or additives to it, and for aggregate. A judicious choice and use of these materials can result in considerable energy and resource savings. Since aggregates and waste materials vary enormously, a study of their *actual* properties is necessary; reliance on research done elsewhere is not possible. The same applies to many durability problems. In other words, Canadian materials to be used in Canada have to be studied in Canada.

By way of comparison, it may be useful to give *approximate* figures for long-term applied research in cement, aggregate and concrete in 1980 in the United Kingdom and in France, given in the author's 1981 report. These are as follows:

	Canada	UK	France
Research as percentage of value of cement production	0.7	1.5	1.5
Research as percentage of GNP	0.0015	0.0045	0.0063

Unfortunately, data on long-term applied research in the U.S. are not available.

It is for the Government, both Federal and Provincial, for universities, and, above all, for industry to decide how much research should be undertaken in the relevant fields. This report is concerned exclusively with establishing what and how much is being done, and where it is done. Hopefully, this information will prove useful in taking appropriate decisions in the future.

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APPENDIX A

LIST OF PERSONS INTERVIEWED AND CONTACTED

ORGANISATION	LOCATION	NAME	POSITION
British Columbia Hydro and Power Authority	Vancouver, British Columbia	Mr E.G.W. Bush	Contracts Preparation Section Hydro-electric Generation Projects Division
British Columbia Ministry of Transportation and Highways	Vancouver, British Columbia	Mr B.W.R. Eastman	Regional Geotechnical and Materials Engineer
	Victoria, British Columbia	Dr D.R. Haughton	Special Projects Engineer, Geotechnical and Materials Branch
Canada Cement Lafarge Ltd	Montréal, Québec	Mr R.W. Suderman	Manager, Research Laboratory and Quality Control
		Mr H.L. Isabelle	Manager, Technical Sales and Product Development
		Mr M. Nisbet	Assistant to Vice-President, Major Investments
Canada Centre for Mineral and Energy Technology	Ottawa, Ontario	Mr V.M. Malhotra	Head, Construction Materials Section, Mineral Processing Laboratory
		Mr W.A. Gow	Chief, Mineral Sciences Laboratories
		Mr V.A. Haw	Deputy Director General, CANMET

Canadian Portland Cement Association	Halifax, Nova Scotia	Mr N.F. MacLeod Mr M.J. Burke	Regional Manager Senior Field Engineer
	Ottawa, Ontario	Mr S. Cumming	Manager, Engineering Services
	Vancouver, British Columbia	Mr R.W. Piggott	Regional Manager
Canfarge Ltée	Montréal, Québec	Mr V. de Benedictis	Assistant Director of Research and Development
Cement and Concrete Association	Wexham Springs, Slough, England	Dr R.E. Rowe	Director-General
Centre de Recherche Industrielle du Québec	Sainte-Foy, Québec	M F. Dugal M G. Auger	Directeur, Secteur matériaux et Procédés industriels Directeur, Service des communications
Centre for Research and Development in Masonry	Calgary, Alberta	Dr E.L. Jessop	Director General
Construction Industry Research and Information Association	London, England	Dr L.S. Blake	Director
Ecole Polytechnique Université de Montréal Departément de Génie Civil	Montréal, Québec	Dr J. Houde	Professeur titulaire
Hardy Associates (1978) Ltd	Burnaby, British Columbia	Dr D.R. Morgan	Manager, Materials Engineering Division

Hydro-Québec	Montréal, Québec	M G. Séguin	Chef de Division Contrôle béton Structures et Mecanique
Klohn Leonoff Ltd	Calgary, Alberta	Dr L.E. Rodway	Head, Materials Engineering Division
Laboratoire de Béton Ltée	Montréal, Québec	M A. Bisaillon	Président
B.H. Levelton and Associates Ltd	Vancouver, British Columbia	Mr P.T. Seabrook	Consulting Engineer
Manitoba Hydro	Winnipeg, Manitoba	Mr K.A. Lenz	Concrete Engineer
McGill University Department of Civil Engineering	Montréal, Québec	Dr M.S. Mirza	Professor
Ministère des Transports Laboratoire Central	Sainte-Foy, Québec	M J.R. La Haye	Directeur de la Recherche et du Contrôle
		M G. Dallaire	Chef de la Division Sols, Agrégats et Textile
		M G. Fréchette	Chef du Laboratoire
Ministry of Transportation and Communications, Research and Development Branch	Toronto, Ontario	Mr P. Smith	Director
		Mr D.G. Manning	Senior Research Officer
		Mr A. Rutka	Principal Research Engineer
		Mr J. Ryell	Head, Concrete Section, Engineering Materials Office
National Boring and Sounding Inc	Montréal, Québec	Dr G. Haddad	Chief, Materials Control
National Research Council	Ottawa, Ontario	Dr V.S. Ramachandran	Head, Building Materials Section, Division of Building Research

New Brunswick Department of Transportation	Fredericton, New Brunswick	Mr G. Keenan	Assistant Highway Director
Nova Scotia Power Corporation	Halifax, Nova Scotia	Mr A. Douma	Manager, Civil Engineering, Thermal Engineering Department
		Mr G.F. MacKenzie	Civil Engineer, Thermal Engineering Department
Nova Scotia Technical University, Department of Civil Engineering	Halifax, Nova Scotia	Dr J.G. Potyondy	Professor
Ontario Hydro Research Laboratory, Civil Research Department	Toronto, Ontario	Mr J.N. Mustard	Manager
		Mr V.R. Sturrup	Supervising Engineer, Masonry Section
		Mr T.J. Carmichael	Geotechnical Engineer
		Mr P.K. Mukherjee	Engineer, Masonry Section
Prairie Farm Rehabilitation Administration	Saskatoon, Saskatchewan	Mr N. Peters	Chief, Geotechnical Division
		Mr J.R. Scoular	Concrete and Quality Control Engineer
Portland Cement Association	Skokie, Illinois	Mr M.J. Catani	Director, Building Division
Queen's University Department of Civil Engineering	Kingston, Ontario	Dr B.B. Hope	Professor
Research and Productivity Council	Fredericton, New Brunswick	Dr D. Abbott	Head, Department of Applied Sciences
Standard Slag Cement Co.	Fruitland, Ontario	Mr G.V. Phillips	Vice-President
Sternson Ltd	Brantford, Ontario	Mr N.P. Mailvaganam	Director, Research and Development
Trow Limited	Ottawa, Ontario	Mr J.A. Bickley	Vice-President

Université Laval, Département de Génie Civil	Sainte-Foy, Québec	Dr L. Lachance	Professeur titulaire
Université de Sherbrooke, Département de Génie Civil	Sherbrooke, Québec	Dr P.-C. Aïtcin	Professeur
University of Alberta, Department of Civil Engineering	Edmonton, Alberta	Dr J. MacGregor	Professor
University of British Columbia, Department of Civil Engineering	Vancouver, British Columbia	Dr S. Mindess	Associate Professor
University of Calgary Department of Civil Engineering	Calgary, Alberta	Dr M.A. Ward Dr R.C. Joshi Dr C.D. Johnston	Professor and Head of Department Professor Professor
University of New Brunswick, Department of Civil Engineering	Fredericton, New Brunswick	Mr T.W. Bremner	Professor
University of Saskatchewan, Department of Civil Engineering	Saskatoon, Saskatchewan	Dr K.W. Nasser	Professor
University of Toronto, Department of Civil Engineering	Toronto, Ontario	Dr G. Heinke Mr R.H. Mills Dr J. Timusk Dr S.M. Uzumeri	Professor and Chairman of Department Professor Associate Professor Professor
University of Windsor, Faculty of Engineering	Windsor, Ontario	Dr C. MacInnis	Dean
Warnock Hersey Professional Services Ltd	Montréal, Québec	Dr R. Farsky	Manager
N.G. Zoldners	Ottawa, Ontario	Mr N.G. Zoldners	Consulting Engineer

ABOUT THE AUTHOR

Adam Neville, P.Eng., has been Principal and Vice-Chancellor of the University of Dundee, Scotland, since 1978. He holds the degrees of B.Sc. (First Class Honours) in Civil Engineering, M.Sc., Ph.D. and D.Sc. of the University of London and D.Sc. of the University of Leeds; he is a Fellow of the Royal Society of Edinburgh.

Following full-time professional experience, he was Professor of Civil Engineering in Nigeria, and Saskatchewan, and later was Dean of Engineering in the University of Calgary, where he also served as Dean of Graduate Studies. In 1968 he became Head of the Department of Civil Engineering in the University of Leeds, England.

Dr Neville has acted as a consultant to industry and governments in the United Kingdom and abroad. He was among those first elected Fellow of the American Concrete Institute and, in 1973, was the first recipient of the Arthur R. Anderson Award of the American Concrete Institute for "outstanding contribution to understanding the behaviour of concrete through research, publications, and teaching". Dr Neville has published extensively, including six books on concrete structures and technology, structural analysis, and statistical methods. His principal books have been translated into nine languages and are in use in many countries.

In 1973, Dr Neville prepared for the Department of Industry, Trade and Commerce a report on the feasibility of establishing in Canada an Institute of Concrete Construction. In 1981, at the request of CANMET, he compiled a report on Long-Term Applied Research in Construction Materials of Mineral Origin in Canada with Particular Reference to CANMET.